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SOME TIME AND SPACE RESOLUTION REQUIREMENTS FOR SPACE OCEANOGRAPHY*

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ABSTRACT

Analyses of photographs from manned space flights and the related oceanography have led to determinations of the spatial resolution and intervals of repetition necessary for the optimum utilization of space-derived, remotely sensed data of certain ocean-surface features.

Coastal waters, both continental and insular, place the greatest demands on teh space system. In these inshore waters, ocean-surface features of 25 square kilometers or larger must be viewed once every 24 hours, on a temperature grid of 10 kilometers, with a feature-boundary definition of 100 meters. These requirements must be applied only to precise geographic localities, if excessive data handling is to be avoided.

Coastal eddies that form sequences of von Kármán vortices are examples of ocean-surface features that have periods, sizes, and sufficient energy to contribute significantly to local environments. A cost-benefit study of three submarine outfalls that carry 1 billion gallons of sewage to the sea indicated a $1 million per year advantage if daily data were available on the near-shore eddy system.

INTRODUCTION

The ground resolution and repetition intervals required for viewing the ocean from space are not defined as readily as they are for viewing the natural features of the land. The sea surface has little relief, and the turbulent systems that exist cannot be seen from the surface. Consequently, before the manned space flights of NASA (National Aeronautics and Space Administration), we had only speculations with which to attempt definitions of time and space resolution.

It was recognized, of course, that the sea surface emits energy in various wave lengths which could be remotely sensed. Further, it was clear that shores and shoals could be photographed. We did not really know, however, the totality of what might be "seen" (Ewing, 1965).

Detailed analyses of Gemini photography answered the question "What can be seen?" to a reasonable extent (Stevenson, 1968a; Stevenson and Nelson, 1968). Until the Apollo flights in April, October, and December 1968, and March 1969, however, a sufficient number of repeated pictures of the same ocean area were not available to determine a suitable repetition interval.

COASTAL SEAS FROM SPACE

Waters where the greatest and most rapid changes take place are adjacent to continents and islands. The best example of a significant, moving water mass is probably the coastal eddy. These rotating currents always form in response to the interference of the land boundary with a horizontal flow. Where the structure in the horizontal flow or stream is an island, the eddies may form from both sides, as counter-rotating, von Kármán vortices. Along major coastlines, however, single-vortex sequences form downstream from the point of origin.

On October 22, 1968, the Apollo 7 astronauts looked down upon Biak Island, north of New Guinea. The sun reflected brightly from the island, the surrounding waters, and the fringing coral reefs. Long, low ocean swells that approached the north shore of Biak, and a series of eddies that flowed northwestward with the monsoon-driven current could be seen in the glitter pattern on the sea surface (Figure 1).

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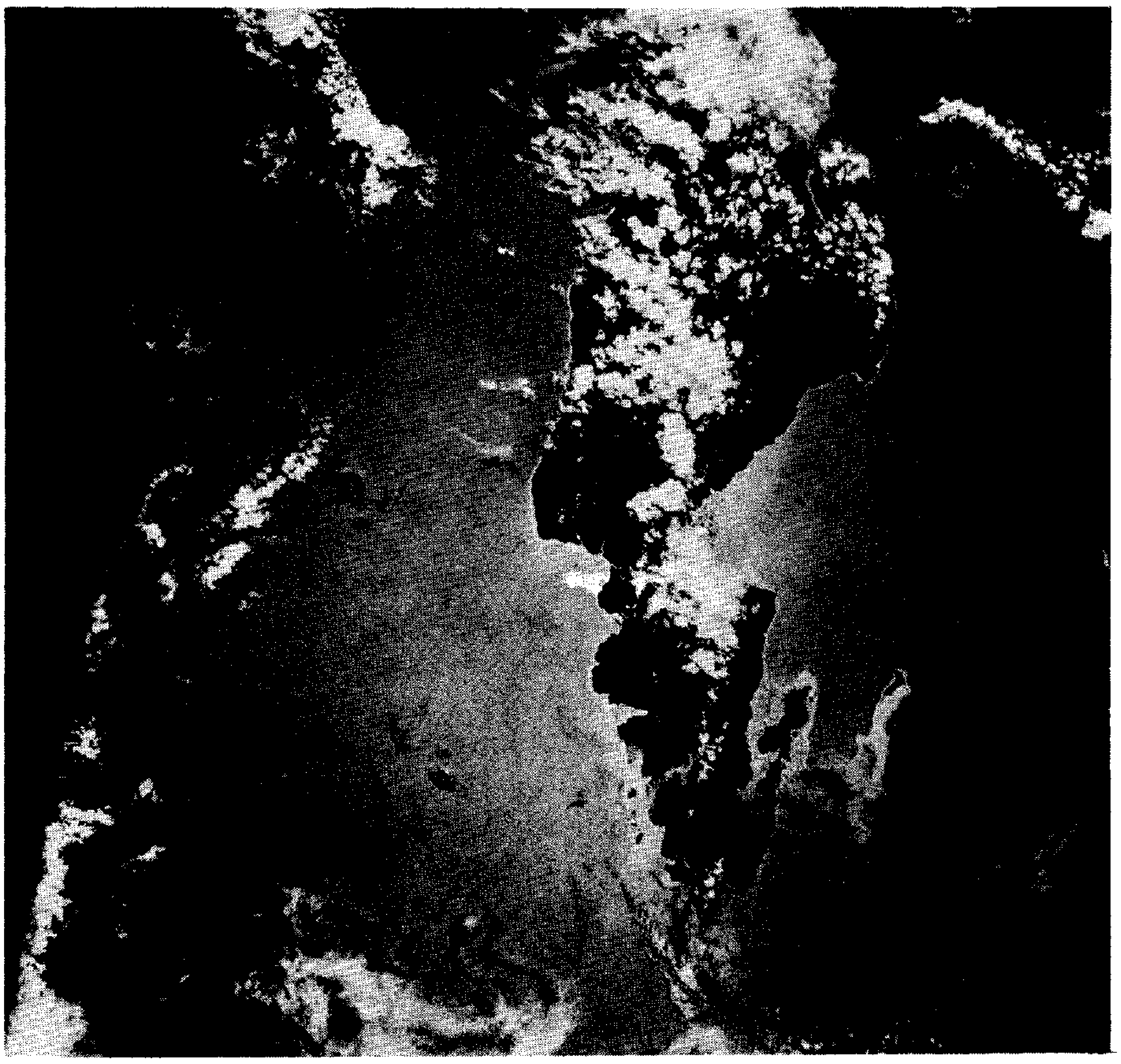

Figure 1 Indonesia: Biak and Supiori Islands, taken during the flight of Apollo 7, October 22, 1968, 02:19 Greenwich Mean Time, from an altitude of 115 nautical miles. The Apollo 7 astronauts used a Hasselblad 500 C camera, modified by NASA, with a Zeiss Planar, 80 mm. focal length, f/2.8 lens, and Kodak SO-368, Medium Speed Ektachrome film. (NASA-Manned Spacecraft Center color photograph AS7-4-1607.)

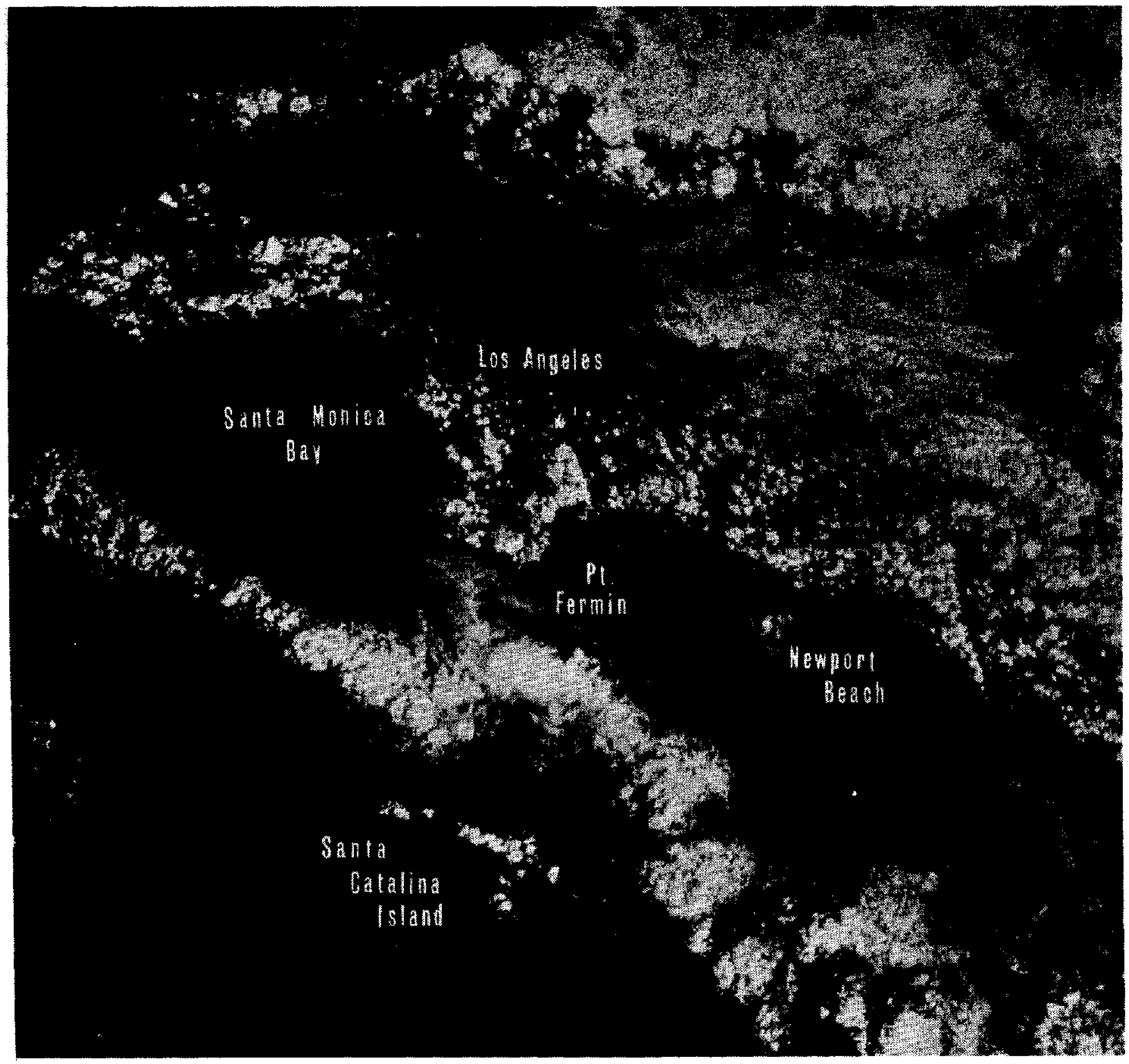

Figure 2 California, San Nicolas and Santa Catalina Islands, and Los Angeles, taken during the flight of Apollo 9, March 9, 1969, 18:01 Greenwich Mean Time, from an altitude of 105 nautical miles. The Apollo 9 astronauts used a Hasselblad 500 C camera, modified by NASA, with a Zeiss Planar, 80 mm. focal length, f/2.8 lens, and Kodak SO-368 Ektachrome film. (NASA-Manned Spacecraft Center color photograph AS9-22-3436.)

The swells, visible to the astronauts because of the reflection of the sun from the wave slopes, had crest-to-crest lengths of 300 meters. They were approaching from due north, from the Philippine Sea, and clearly were "old" swells -- the continuous crest-lengths were as long as 50 kilometers.

The coastal eddies formed as turbulent vortices (von Kârmân vortices) downstream from the headland on the east side of Wari Bay. One eddy, rotating counter-clockwise, was forming in the embayment and bringing water into Wari Bay from 15 kilometers offshore. Remnants of two more vortices were visible to the west in the sun's reflection. These túrbulent, rotating waters had created a distinct divergence some 8 to 15 kilometers from the coast and a well-defined convergence in outer Wari Bay.

Little is known about the sequence of formation or the lifespan of turbulent eddies formed along current boundaries or coastlines. None has been studied successfully from research vessels, and man did not have the capability to view the vortex sequences in their entirety before the acquisition of photographs from manned spacecraft.

Since 1965, a number of such eddies in the ocean have been photographed during the Gemini and Apollo space-flight series. The turbulent vortices were always seen easily in the sun's glitter pattern. Roughness of the sea surface differs according to whether the currents flow with the wind or against it. Consequently, outlines of vortices are extremely well defined by the sharp boundaries between the smooth and rough waters.

Some understanding of coastal eddies, their origin and lifespan has been gained from space photographs. The energy required to generate the rotating vortices is derived from coastal currents. The eddy begins to form at a headland and then moves downstream at a speed about one-fifth that of the coastal current. The eddies along the north coast of Biak represent a series that formed over a period of 3 days. The youngest vortex in Wari Bay was about 24 hours old.

The convergence between the two vortices in Wari Bay probably remained in the surface waters for 5 days, or more, and would have developed, by then, a large flotsam line. The offshore divergence is, no doubt, a constant feature of the waters north of Biak throughout the summer monsoon. The energies involved are sufficient to produce vertical turbulence to depths of 90 meters, thus creating a significant upwelling.

AN APPLICATION

Three submarine outfalls along the coastline of greater Los Angeles, California, carry 1 billion gallons of sewage to the sea daily. The outfalls are in Santa Monica Bay, at Point Fermin, and at Newport Beach (Figure 2). At each locality, millions of dollars were spent to design and build a system that would not require the tremendous expense of total treatment and the daily use of chlorinating compounds. The Santa Monica Bay discharge is the largest and most sophisticated. Its massive diffusers are 8 kilometers from shore; the great volumes of sewage introduced into the sea create neither a health hazard nor an unaesthetic scene. At Point Fermin, the outfall extends into deep (80 meters) turbulent water, and no detrimental water conditions prevail.

Circumstances are different, however, at Newport Beach. The outfall is in shallow water (20 meters) and is only 2,000 meters from shore. Although the near-shore circulation usually mixes the discharged effluent sufficiently and transports it along the coast without creating a hazard, currents occasionally carry the effluent to the local beaches quickly and without mixing by waves. Under these conditions, were it not for the introduction of chlorine into the sewage, bacteria would not be reduced to limits established by California State regulations. Although not needed 75% of the time, chlorine is mixed continuously with the sewage because of the unpredictability of the occurrence of these adverse currents (Stevenson, 1962, 1963).

The conditions under which the adverse currents at New port Beach occur suggest that they are the result of eddies migrating downstream, southward, from Point Fermin. If a steady flow passed the headland, as off the north coast of Biak in October 1968, the occurrence of the eddies and shoreward currents could be predicted. The current is not a steadily flowing stream, however, but rather is highly variable in speed and consistency because of the influence of local land and sea breezes. Consequently, the vortices have no regular interval of formation, and the influence on the effluent discharge cannot be forecast.

From space, however, the formation and southward migration of the vortices could be sensed and the associated currents could be precisely defined each day. Although a satellite can hardly be put into orbit to provide information to only one municipal sanitation district, the capability of a worldwide, oceanographic satellite system clearly could provide this service, in addition to innumerable others. Further, one can hardly consider a more practical application than daily data transmission.

to a local sanitation district office so that proper treatment of sewage outflow can be programmed efficiently and economically.

REQUIREMENTS

Suitable data on various characteristics of the ocean surface can be acquired from remote sensors in orbiting spacecraft. Requirements for spatial resolution and intervals of repetition vary, but are most stringent for waters adjacent to continents, islands, and major ocean currents.

The amount of spatial resolution for temperature points depends on the area being photographed. In coastal waters, around islands, and along borders of currents, 10 kilometers is necessary, whereas in the open ocean, 100 kilometers is adequate. Because of the short interval of time (usually 1 to 100 seconds) required for the spacecraft to pass over the waters where the greatest density of temperature points is needed, the scan rate of the temperature sensor, which must remain constant, should be set to meet the strictest requirements. The change in density of the temperature points will be in the computer program.

Ocean-surface features smaller than 25 square kilometers that are produced by horizontal or vertical turbulence are generally nonsignificant except as they contribute to the large system. Feature boundaries with widths of but a few hundred meters, however, must be adequately defined. Furthermore, because detailed wave trains photographed by the astronauts are useful in recognizing sea-floor topographic features (Stevenson, 1968b), sensing resolutions must provide for waves from 75 to 350 meters long. A workable resolution of waves and feature boundaries is, therefore, about 100 meters.

The interval of repetition must be shorter for the active portions of the oceans than for the vast mid-ocean areas. The formation of eddies within a 24-hour period, as off Biak, implies an interval no greater than 1 day. Once the continuity of eddy growth is known, however, the repeated look might be necessary only every other day -- or every five days. The problem now is that we simply know too little about the time interval of significant changes along the active zones of water motion in the seas.

With the uncertainty in mind concerning the rates of change in coastal areas, the experimental space program clearly demands the rational discrimination of man. The success of a workable earth-resource space system will depend, therefore, on well-conducted, logically designed, manned-orbiting surveys that are coupled with simultaneous oceanographic cruises, judiciously undertaken to complement the orbital paths and times of the spacecraft.

KEY WORDS

Coastal eddies, oceanography, sewage, space oceanography, R.E. Stevenson.

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